Landscape Assessment (LA)

How To, Glossary, and Appendix

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LANDSCAPE ASSESSMENT HOW TO

How To Record a GPS Location

Basically, there are a number of options today for GPS receivers and ways to acquire locational data. Here are recommend protocols on only a few issues.

Acceptable accuracy

The two-dimensional accuracy of X (Easting), Y (Northing) coordinates reported by the GPS should be less than 10 meters, preferably less than 7 meters. There is no procedural requirement on elevation, or the Z coordinate.

Geodetic Datum

The more accurate and more recent NAD83 should be selected, unless there is strong need to use the data predominantly within a local GIS, and the local standard is for some other datum. For example, many National Park Service sites still use NAD27 in order to reference data taken from their older base maps. These were some of the first areas mapped with USGS 1:24,000 quadrangles. In any event, it is very important to note the datum used for plot location, so conversions can be made if necessary.

When digitizing a single point

Y-Code receivers like Rockwell's PLGR, should be set to an averaging mode and allowed to log a number of points until the coordinates stabilize. At which time, the plot center is either jotted down or saved in memory. These receivers are only available to approved federal government employees.

P-Code receivers like Trimble's Pathfinder and GeoExplorer, or various Garmin models should be treated similarly only if "selective availability" is off. If "selective availability" is on, a differential correction should be used. Set the receiver to log and save a hundred or so points for each plot center. Options are to do differential correction "on the fly", or later by receiving suitable reference control data from a surveyed base station. You will have to check with GPS-knowledgeable people in your area to find how to access local base station data.

How To Take Plot Photos

It is a good idea to take photos *after* completing the rating exercise, when one is most familiar with plot burn conditions. There are many approaches to this, but some recommended procedures include the following. Use a high-resolution digital camera, or a 35 mm camera with color slide film, ASA of about 125. Take at least two photos approximately 180 degrees opposite one another, showing the plot center and about half of the plot in each. Avoid taking photos directly toward the sun. Include a signboard for scale, and to identify the date and plot number in the picture. As time or objectives allow, take any number of photos targeting features of interest; e.g. typical charring patterns on substrates or trees, and re-growth of perennial herbs and shrubs. Try to capture tree canopy effects as well as ground effects.

How To Name Files for Burn Remote Sensing

Generally, it is beneficial to keep filenames as concise as possible, and be consistent from analysis to analysis. Filenames can get quite involved, but try to include some indication of data content and level of processing, to simplify retracing steps and file lineage. Since these data are a time series, it is helpful to use names that sort into a date sequence. Here are some suggestions:

YYDDD.bB - *Raw Landsat bands* can be named by date and band number, most simply with a 2-digit year (four digits if necessary), 3-digit Julian day (2-digit month and 2-digit day, if necessary), "b" for band, and the Band number, B.
Example: 01179.b4 designates Band 4 of a scene from 2001 Julian day 179, or 28 June.
Scenes of the same path have the same date sequence, so if scenes of the same path and date are kept separate and not seamlessly patched together (as could be), names may become ambiguous when used in the same analysis. In that case, a designator for row number can be added. Scenes of the same path that will always be used in separate analyses (such as one from California and one from Montana) are not a problem. They can be separated within directories of the file system. Landsat TM and ETM+ data will never be acquired from the same path/row on the same date, so redundancies should not occur between the two satellites. If it is found useful to distinguish them, a prefix of "t" or "e", respectively, may be used (e.g. t01171.b4 and e01179.b4).

YYDDD.rB and YYDDD.trB - *Band reflectance* and *transmittance-corrected reflectance* data can use the same designation above, with substitution of "r" or "tr", respectively, in the extension. Example: 01179.r4, 01179.tr4

YYDDD.n or nYYDDD - The normalized burn ratio for scene YYDDD carries the same form as above, but with an "n" as an extension or as a prefix.

dYYDDDYYDDD.n or dnYYDDDYYDDD - The name identifies the operation (“d” for delta or difference), the two scene dates, and the index used in the difference (“n” for NBR). Differencing presents many possible scene combinations, so it helps to keep scenes explicitly identified in the name.
Example: d0018201179.n = NBR difference between 1 July 2000 and 28 June 2001, i.e. Julian days 182 and 179, respectively.

Variations might include different indices such as "v" or "vi" for the NDVI, or subsets of scenes that may require added codes for individual burns. A classification or rescaling of continuous data might add a "c" or "r" to the extension, such as dnYYDDDYYDDD.c to represent a file containing the ordinal severity classes derived from the delta NBR.

How To Handle Reflectance

This section is additional comment on the reflectance algorithm described in Chapter 3 of the LA Method.

Eq. LAHT-1 $$L_i = DN_i * G_b + B_b$$

The radiance term (L_i) would be straight forward, except for the fact that gains and biases (G_b and B_b) have been reported differently over time, depending on the satellite generation, post-processing software, and the vendor.

It is important to read the technical documentation accompanying the data to understand what units are being used, and whether maximum and minimum radiance is being reported instead of true gain and bias. Generally TM data from EOSAT/Space Imaging Corp., a private corporation, is processed in "Fast Format", and reports gain and bias in milliwatts per square centimeter per steradian per micrometer. For a period, though, those values were actually maximum and minimum radiance, so a conversion is required to generate appropriate G_b and B_b. Recent procurement of TM and ETM+ data from the USGS EROS Data Center, on the other hand, will most likely be processed with NLAPS or L7 software, which generate gain and bias in watts per square meter per steradian per micron (a micron is equivalent to one micrometer).

Eq. LAHT-2 $$R_i = (L_i * \pi * d^2) / (\mathrm{Esi}_b * \cos(z_s))$$

In the reflectance term (R_i), the exoatmospheric solar irradiance, Esi_b is the mean irradiance striking the uppermost atmosphere per-bandwidth, b. It is important for Esi_b to be in the same units as the gain and bias used to calculate radiance. The Esi_b also differs slightly between Landsat satellites, as the bandwidths are slightly different. Generally, for Landsat 5 TM data processed by EOSAT/Space Imaging Corp., Esi_b would be applied in milliwatts *per* square centimeter *per* micrometer:

Band:	1	2	3	4	5	7
L5, TM Esi_b :	195.7	182.9	155.7	104.7	21.93	7.452

For TM and ETM+ processed by the USGS EROS Data Center, Esi_b values are reported in watts *per* square meter *per* micron (a micron is equivalent to a micrometer):

Band:	1	2	3	4	5	7
L5, TM Esi_b :	1957.	1829.	1557.	1047.	219.3	74.52
L7, ETM+ Esi_b :	1970.	1843.	1555.	1047.	227.1	80.53

Note: Watts *per* square meter *per* micron is a factor of 10 greater than milliwatts per square centimeter per micron.

The Esi_b decreases steadily as wavelength increases to the right. For example, there is only about 1/13th the amount of incoming irradiance in Band 7 as in Band 4. Thus, it would be difficult to associate the two bands directly, since Band 7 is naturally so much darker by comparison. The ratio calculated by reflectance, though, normalizes for this initial difference in irradiance magnitude. It produces a value between 0.0 and 1.0, which is then comparable between the bands. Reflectance is functionally equivalent to a simple percentage calculation, associating the amount of detected light with the total available.

The factor, d^2, makes minor adjustment in exoatmospheric solar irradiance, Esi_b, due to orbital eccentricity, or the daily deviation from average distance between earth and the sun (see the **LA Glossary**). The d^2 ranges between 0.9666 and 1.0350, and is closest to 1.0 in early October and early April. For a given day, it can be obtained from a look-up table. Refer to a reference dealing with solar radiation (e.g. Muhammad Iqbal, 1983. *An introduction to solar radiation.* Academic Press, New York.).

In its most basic form, if one discounts surface topography and sun angles, "at satellite" reflectance boils down to a simple ratio of radiance (or detected brightness) over the amount of available incoming solar radiation per bandwidth, in other words:

Eq. LAHT-3 $$R_i = (L_i * \pi * d^2) / Esi_b$$

All other factors in the algorithm simply modify Esi_b in ways to more realistically gauge the amount of incoming radiant energy that has potential for reflection off the earth's surface. That, of course, initially involves the angle of the sun in relation to zenith, as is the case assuming a flat surface:

Eq. LAHT-4 $$R_i = (L_i * \pi * d^2) / Esi_b * \cos(z_s)$$

This denominator simplifies the influence of incidence angles on Esi_b, where only the sun zenith angle of a particular scene, z_s, is applied (see the **LA Glossary**). When the sun is directly overhead, z_s = 0 degrees and $\cos(z_s) = 1$, so the entire quantity of Esi_b is available for detection. As the sun angle moves away from zenith, $\cos(z_s)$ decreases, serving to decrease the amount of available light (Esi_b) for detection. In a more complex form, below, the algorithm incorporates topographic angles, which more accurately model the amount of incoming light hitting a pixel's surface. That, however, is deemed unnecessary for NBR analyses, as NBR per-pixel normalization cancels those factors out, so use of either reflectance algorithm is mathematically equivalent.

Reflectance Incorporating Topography

The following is provided only for added understanding of reflectance, but is not required to complete the analysis of burns using the NBR. Such an approach may be preferred in other cases when normalized band ratios are *not* used, and comparisons between scenes depend directly on calculated per-band reflectance. The more complete rendering of reflectance has sun direction and topographic factors built into the derivation:

Eq. LAHT-5 $$R_i = (L_i * \pi * d^2) / (\mathrm{Esi}_b * (\cos(z_s) * \cos(slope_i) + \sin(z_s) * \sin(slope_i) * \cos(a_s - aspect_i)))$$

where, a_s is the per-scene sun azimuth angle, and $slope_i$ and $aspect_i$ are the per-pixel topographic variables derived from a DEM. Note, aspect in degrees from north, has "flat" re-assigned to equal the sun azimuth angle; such that, $a_s - aspect_i = 0$ for flat pixels.

When a DEM is available, the added terms in the denominator adjust z_s to approximate the actual incidence angles created by interplay of sunlight on topography. Generally, the terms increase available light as slope angles increase and aspects face towards the sun. Conversely, reflective light potential decreases as slopes steepen and aspects face away from the sun. On a flat surface, the topographic terms reduce to 1.0, so again, Esi_b is only modified by $\cos(z_s)$.

Since Esi_b and terms associated with modifying potential irradiance occur in the denominator, the effect of angular adjustments on reflectance, R_i, is the inverse. That is, a given radiance value, L_i, will yield higher reflectance on a slope facing away from the sun than the same L_i on a slope facing towards the sun. This occurs because available incoming radiation is modeled to be less on the slope facing away from the sun. The given radiance value indicates proportionately more incoming light is being reflected there than on the slope facing the sun, and the surface therefore is more highly reflective. The net effect of this transformation tends to remove some of the contrast created by topographic shading, so images appear somewhat "flatter". As it were, the distribution of pixel values is now on a spatially "level playing field".

The natural range of R_i should be 0.0 to +1.0, or, by some order of magnitude. (e.g. To scale reflectance from 0 to 1000). Unfortunately, this reflectance model tends to overcorrect when *all* the following conditions are true: 1) surfaces face nearly directly opposite the sun ($a_s - aspect \approx 180^\circ$); 2) slopes are steeper than the angle of the sun above the horizon ($slope_i > 90 - z_s$); and 3) detected radiance, L_i, is above zero. In these cases, the product of the denominator evaluates to very near zero and, with some level of detected L_i, the quotient R_i becomes unrealistically high (either positive or negative). This occurs because the algorithm assumes total potential for illumination comes only from Esi_b, and thus solar irradiance is essentially absent from areas in shadow. In reality, however, the situation demonstrates that some contribution to detected radiance, L_i, may come from reflected light off surrounding surfaces or the atmosphere, and not only from Esi_b directly. Overcorrecting may also arise from mis-registration, error in the digital slope and aspect models, or it may indicate clouds, where pixels obviously do not have appropriate slope and aspect angles associated with them.

Ignoring the known errors, which typically can be corrected or excluded from analysis, solutions to the steep shadowed slope problem are variable and potentially complicated. They generally only pertain to a small portion of a scene, however. If those areas are not widespread and/or do not interfere with a particular analysis, it is best just to ignore them, and simply mask out the overcorrected pixels ($R_i < 0.0$ or $R_i > 1.0$) by rescaling them to zero. Then, exclude them from subsequent calculations. Generally, if such pixels are on steep sheltered slopes without sufficient vegetation to warrant concern in burn applications. (Assuming images over mountainous terrain are from mid latitudes, within six weeks of summer solstice.)

If such pixels apparently interfere with acceptable accuracy of objectives, one can reclassify the slope dataset such that slope angles greater than or equal to the angle of the sun above the horizon are reassigned to equal the sun elevation angle minus one:

$$\text{IF } (slope_i \geq 90\text{-}z_i) \text{ THEN } (slope_i = 90\text{-}z_i\text{-}1)$$

This minimally alters the response curve of Esi_b on steep slopes over the range of aspects, but prevents that term from being reduced to zero in the denominator. At the same time, it accommodates a small amount of irradiance (equivalent to one degree of slope) contributing to the brightness of those pixels, which may naturally come from indirect reflected light.

A third option is to filter the topographically corrected solar irradiance of the denominator, to establish a lower near-zero limit. Values less than approximately one percent of Esi_b should be reassigned to a minimum level (the value of 0.01 is flexible, and may be modified with experimentation) equal to about one percent of Esi_b:

$$\text{IF } (t\text{Esi}_b < 0.01^* \text{ Esi}_b) \text{ THEN } (t\text{Esi}_b = 0.01^* \text{ Esi}_b);$$

where, $t\text{Esi}_b$ is the modified incoming solar irradiance per band that accounts for incidence angles from the sun and the earth's surface. To facilitate this, it may be necessary to create an interim raster dataset of $t\text{Esi}_b$ and then employ available GIS functions to make the reassignment. The resulting dataset is then reinserted in the algorithm to complete the reflectance calculation.

Pixels with zero radiance (no detected brightness) will not be affected by these two adjustments, as should be the case, since both the numerator and the quotient will evaluate to zero overall. Other solutions to the problem involve expression of more complex geometry within the algorithm. At this time, we are not prepared to recommend any one in particular, but we would be interested in hearing about practical solutions that have been tried and found successful.

Atmospheric Normalization

1. Determine if transmittance is a factor, and if so, which scene is most affected by atmospheric scattering. The scene less clear (i.e. the one with less transmittance) will be

the one corrected, and become the independent variable in regression analysis performed later. Usually, this scene will exhibit brighter reflectance over dark targets, like lakes, compared to values from the same targets in scenes with greater transmittance. Relative difference in transmittance can be determined quantitatively by comparing pixel reflectance sampled over dark targets. Lower transmittance also appears to decrease contrast, compared to scenes where the air is clear. The most affected bandwidths include the visible Bands (1,2,3), so base comparisons on those bands to enhance differences. (Band 1 is most influenced by atmospheric factors, so use it when comparing single bands). Compare bands between scenes individually as grayscales, in false-color combinations, or by their histograms. The scene with less transmittance should show less variance in the histogram, and a shift to the right or brighter region.

2. Using both scenes for reference, digitize small polygons consisting of a few (50-200) pixels each, which collectively represent areas of low, mid-range, and high reflectance. Each polygon should be restricted to quasi-invariant targets that appear to have the same relative reflectance in both scenes. Targets should not be subject to seasonal changes or other disturbances that normally affect reflectance. Examples of acceptable targets include: 1) lakes or deep shadow for the dark sample; 2) high density mature conifer stands for the mid-range; and 3) rock, snow, or parking lots for the bright sample. Avoid areas that differ noticeably between scenes, such as where clouds occur, or where snowmelt patterns are not the same. Attempt to obtain sample polygons from within about one quarter of the scene surrounding burn study area(s). Sample sizes should be in the range of 4 to 8 polygons and 600 to 1200 pixels per level of reflectance, or more.

3. Extract pixel reflectance values that occur within the set of digitized polygons, for each Band (4, 7) of each scene. Import them to statistics software capable of performing linear and quadratic regression. he statistics data-file should sequentially contain a record for each pixel, with each pixel's reflectance values as the variables (Bands 4 and 7 of one scene, and Bands 4 and 7 of the other scene).

4. Perform curve-fitting operations on each band using both linear and quadratic models to associate the two dates. Assign the evidently less clear scene to the X axis (independent variable) and the scene with greater transmittance to the Y axis (dependent variable), per band. Check that scenes are properly assigned to dependent and independent variables by reviewing the regression coefficients. If they are not, reverse the order of the scenes in the regression analysis.

5. Notice which model best fits the data of each band by reviewing the regression statistics, and a scattergram of plots with regression lines overlaid. If possible, include a 98 percent confidence interval on those plots. Select the regression model that most adequately explains the intra-band differences observed between scenes. This is a judgment call. Generally, one would not resort to the more complex quadratic model, unless it obviously appeared to improve the fit throughout the distribution of points.

6. Remove widely deviant pixels from the sample before further analysis of each band. Such pixels likely differ between scenes due to reasons other than atmospheric clarity, such as

phenology or some kind of disturbance. Use a broad confidence interval (CI) on the regression model just selected per band, like 98 to 99 percent. Determine the breadth of those intervals per band in reflectance units plus-or-minus. Goodness of fit is generally quite high, since sampled pixels have been selected for their comparable reflectance. The typical r^2 should be in the range of 0.93 to 1.00, so even the 99 percent CI will usually be quite narrow. Construct a filter that eliminates records from the statistics data file, if a record has either Band 4 or Band 7 differing between scenes by more than the per-band CI. The objective is to define a set of pixels that shows a consistent trend in reflectance difference between the two scenes, caused only by atmospheric effects.

7. Re-run the selected regression model on the remaining pixels, with deviant pixels removed. Evaluate regression statistics and coefficients. If r^2 value is high, and coefficients indicate essentially no difference between the two distributions per band (for reflectance that is a *slope* in the range of 0.995 to 1.005, and an *offset* of ±0.010.) then atmospheric normalization is probably not necessary, and one can use both original reflectance datasets to calculate NBR. If the r^2 value is too low, or elimination of deviant pixels leaves too small a sample size, consider re-defining the sample polygons, and re-running the regression. The initial sample may contain an excess of non-atmospheric effects or perhaps clouds.

8. Use regression coefficients just derived to transform the bands from the scene with greater atmospheric effects (independent variable, above) and normalize them to the scene with apparently clearer air (dependent variable above). A linear transformation will have the form:

   Eq. LAHT-6 $$R_{Yi} = b_1 * R_{Xi} + b_0 \, ;$$

   Where, R_{Yi} is the new normalized per-pixel reflectance per band, of the scene with less atmospheric clarity. R_{Xi} is the original per-pixel reflectance for that scene (the original independent variable, above), b_0 is the regression coefficient of bias or offset, and b_1 is second regression coefficient for gain or slope. A quadratic transformation will have the form:

   Eq. LAHT-7 $$R_{Yi} = b_2 * R_{Xi}^2 + b_1 * R_{Xi} + b_0 \, ;$$

   Where, variables are the same as above, with the addition of b_2, which is the third regression coefficient for the square of the independent variable.

The resulting band reflectance data, R_{Yi}, are used in subsequent NBR calculations. Interactively on the graphics monitor, take a while to compare the results per band to the original reflectance data, and to the scene not transformed. One should notice only subtle changes in the normalized data, but where visible, they should be in the direction that makes the corrected bands more similar to the scene with high atmospheric clarity, compared to the original bands with low clarity.

LANDSCAPE ASSESSMENT GLOSSARY

Azimuth angle - Reported in the Landsat scene header file, it is the angle in degrees from north of the position of the sun when scene acquisition occurred, relative to scene center.

Band or Bandwidth - A discrete region of the electromagnetic spectrum, representing a range of wavelengths; the breadth of the region is the bandwidth. Sensors usually are designed to record the amount of energy detected within specific regions of the spectrum, hence the derivation of bands. In order of increasing wavelength, the spectrum begins with gamma rays and the ultra-violet, and progresses through the blue, green, and red zones of the relatively narrow visible range. The entire visible range expressed as one bandwidth is considered panchromatic, and would appear like a black-and-white photograph. The near (NIR), middle (short-wave, SWIR), and thermal (long-wave, LWIR) infrared bandwidths follow in a broad region. Beyond infrared regions encompass much of what is used for communication, including microwaves, TV, and the longest, radio waves.

Burn severity – The degree or magnitude of environmental change caused by fire. The change may be represented by single or multiple biophysical variables on a continuous scale from no change to high change. The gradient may be partitioned into nominal levels, such as low, moderate and high. For meso-scale landscape perspectives, it is the degree that fire affected an area or community, measured as a composite value over the horizontal and vertical dimensions of the area. In socio-economic terms, burn severity is often measured by cost or human casualty incurred during and after a fire, including loss of resources. There are usually short- and long-term implications of burn severity, see *fire effects*.

Community - For our purposes, an ecological community, consisting of all plants and animals, as well as the various inert materials, both organic and inorganic, which occupy an area. Generally, a community can be divided into multiple zones with different sub-components (see **stratum/strata**). Groups of communities often have similar, repeatable characteristics that lead to classification of specific community types, often based on dominant species, microclimate, and soil. Landscapes consist of assemblages of different communities.

Eccentricity factor - Variation in the radius of earth orbit that accounts for daily deviation from an average circular orbit, as applied to **reflectance**.

Eq. LAHT-8 $$d^2 = 1 / E_o \;;$$

where d^2 is the eccentricity factor, and E_o is the eccentricity correction quotient for day o.

Eq. LAHT-9 $$E_o = (r_o / r)^2 \;;$$

where r_o is the sun-to-earth orbital radius on day o, and r is the mean orbital radius over a year period.

Edaphic - Characteristics resulting from properties of the soil.

Fire effect – Any result of fire. It may be related to biological or physical components of ecosystems, or to ecological processes that in turn impact biological or physical components. It may also be related to biophysical systems, such as communities, the atmosphere, or landscapes.

Fire effects, initial or first-order – Those effects manifested on the biophysical components or systems that existed at the time of fire. First-order fire effects are the direct result of combustion processes, including plant injury and death, fuel consumption and smoke production (Modeling fire effects, Elizabeth D. Reinhardt, Robert E. Keane and James K. Brown. International Journal of Wildland Fire 10(4) 373 – 380)

Fire effects, long-term or second-order – Time-dependent responses to fire over the long term, where initial fire effects are influenced by many biophysical factors subsequent to the fire, such as: 1) seed-bank species and proximity to post-fire seed sources; 2) localized site characteristics like topography and soils; 3) subsequent climate; and 4) secondary effects from erosion and mass wasting.

GIS - Geographic Information System(s). Integrated software, hardware and data used to store and manipulate information that combines thematic and locational attributes about geographic features.

Herb - Annual, biennial or perennial plants, including grasses, that do not develop persistent woody tissue, but tend to die back and regrow (or reseed) on a seasonal basis.

Histogram - A frequency distribution over a range of values. For example, the number of pixels that occur at each numeric value of reflectance. May be presented in tabular or graph form.

Hydrography - The geography of hydrologic features, principally surface waters comprising all variations of lakes, rivers and streams; as well as the drainages within which these features are nested.

Irradiance - The quantity of light reaching earth, as measured in energy units per unit area per bandwidth, e.g. watts per square meter per micron. The amount of incoming radiation available for detection.

Multi-spectral - Data received by a sensor, recorded as brightness values that occur within a few (usually 4 to 20) relatively narrow ranges, or **bandwidths**, of the electromagnetic spectrum. Each band is recorded independently, but simultaneously from the same surface area, providing information about surface composition. The number of bands and the bandwidths define the sensor's spectral resolution. Spectral values recorded in many (100 to 300) relatively narrow bands are considered hyper-spectral, and more closely approximates the continuum of energy observed in the spectrum.

Normalized Difference Vegetation Index (NDVI) - A normalized difference of Landsat Band 4 (NIR) and Band 3 (visible red), expressed as:

Eq. LAHT-10 $$\mathrm{NDVI}=(R4-R3)/(R4+R3)$$

The index is directly related to the amount of green biomass, per unit area. It has been used as a measure leaf area, primary plant production, and when temporally differenced, as an index of dryness or drought.

Pixel - Literally, "picture element". The smallest unit area that has a data value assigned to it. Pixels within an image generally are all the same size, and arranged in a contiguous rectangular grid of rows and columns. Spatial orientation of the grid can be registered to a map projection, so that individual pixels may be located on the ground.

Radiometric - Having to do with measurements related to the intensity of radiant energy.

Radiance - The brightness detected by a sensor in a particular bandwidth.

Raster - A digital image stored in one of many grid cell formats, where the cells (that is, pixels) are represented as binary numeric values referenced by byte position within the file. Byte position can be translated into pixel row and column, such that the grid models some 2-dimentional space.

Reflectance - For our purposes, a per-pixel ratio of the amount of reflected energy measured per bandwidth by the satellite, to the amount of available incoming solar radiation per bandwidth. The latter quantity is the exo-atmospheric solar **irradiance** per bandwidth, a constant, modified by the daily eccentricity of earth-sun distance and the incidence angle of sunlight striking earth and reflecting back to the satellite. Incidence angles may simply incorporate the solar zenith angle derived from the Landsat scene header file, or may be refined by also including the solar azimuth angle, and the per-pixel slope and aspect angles derived from a Digital Elevation Model (DEM).

Scattergram - A two-dimensional plot of points with X- and Y-axes assigned respectively to an independent and a dependent variable. Point locations indicate the value observed in one variable at a given value of the other variable, for example, the Band 4 reflectance of a pixel before fire, versus Band 4 reflectance of that same pixel after fire.

Spatial heterogeneity - The mix and diversity of identifiable landscape features, incorporating not only the types of features, but also their size, shape and location in relation to each other. Useful dimensions or units include: number of different patches; patch size, shape and diversity; fractal dimension (one of several ratios of patch size to perimeter distance); juxtaposition (a weighted length of edges surrounding a central area); and contagion (the degree of clumping). For burn heterogeneity, such measures indicate how complex a burn was, and the prevalence of particular levels of burning.

Spatial resolution - The aerial dimension of the smallest element that can be resolved, or identified on a map, image, or ground surface. For Landsat TM and ETM+ sensors, it is approximately 30 x 30 meters square, which constitutes a **pixel**. Smaller features, or parts of multiple features that co-occupy a single pixel, become averaged together to make up the overall spectral signature recorded for that area (see **multi-spectral**).

Spectral Signature - The combined values of one or more **bands** that uniquely define a particular area or feature, such as an individual pixel or a type of vegetation. The bands and the ways they are combined are highly variable and dependent on user objectives. It may be as simple as a range of values from one band, or as complex as involved mathematical algorithms incorporating many bands, as in clustering techniques. Usually statistical reliabilities are associated with signatures to help the analyst determine which ones best identify the features of interest.

Stratified Sampling - Where the entire population to be sampled is divided into subgroups, and samples are drawn by rules pertaining to each subgroup. For the population of pixels representing a whole burn, one might divide the area by drainages, or by perceived severity levels, and choose a number of sample points from each area. The draw might be done either randomly or in equal numbers per subgroup.

Stratum or strata - Referring to one or more layers of a community, arranged vertically and having a continuous sequential order from below-ground to ground-level, and from ground-level to the top of the uppermost vegetative canopy. Strata typically are based on within-stratum similarities of physical organization, species composition, and/or microclimate. Heights of strata usually differ, increasing upward. A few to many strata may be used to characterize a given community, depending on recognizable traits and consistency of occurrence, as well as objectives for doing so. For burns, we identify strata that likely influence fire behavior, and show potentially unique responses to burning.

Transmittance - For our purposes, a ratio of the amount of energy actually passing through the atmosphere and reaching the ground, to the maximum amount that can possibly reach the ground. It designates the clarity of the atmosphere, and is inversely related to the amount of atmospheric scattering. When transmittance equals one, the air is perfectly clear. Progressively lesser values indicate increased scattering of light, as influenced by clouds, humidity, and particulates, including smoke. Areas of low transmittance generally appear brighter than areas of high transmittance, because the atmospherically scattered portions of light are not diminished by absorption from ground surfaces. Transmittance varies by **bandwidth**; a property of energy, such that capacity for atmospheric penetration increases with wavelength. For Landsat, this means that infrared Bands 4 through 7 are less influenced by scattering factors than visible bands.

UTM - The Universal Transverse Mercator is a map projection. Widely used in natural science applications, it is suitable for maps of 1:100,000 and greater scale, e.g. 1:24,000. Each hemisphere of the world is divided into 60, 6-degree, zones by longitude. Within each zone, the reference is an X,Y equidistant grid in meters, with origin at the lower-left zone corner (western most point on the equator). Coordinate pairs are given in meters northing and easting (e.g. 5437689N, 278334E), increasing from the origin to the north and to the east, respectively. For more UTM information, see:

http://mac.usgs.gov/mac/isb/pubs/factsheets/fs15799.html

Vector - Geographic data represented as numeric X, Y coordinates, and usually some attribute identifier. Vector data define features by point, line, or polygon topology, and are displayed as such on maps or graphics.

Zenith angle - The angle of the sun in degrees from zenith (i.e. the position directly overhead at scene center) when scene acquisition occurred. The sun elevation angle, *e*, is reported in the Landsat scene header file as degrees above the horizon. To obtain the zenith angle, subtract that value from 90 degrees: ($z_s = 90 - e_s$).

LANDSCAPE ASSESSMENT APPENDIX A: RECENT LANDSAT SATELLITES

Landsat 5

Launched in 1984, Landsat 5 carries the Thematic Mapper (TM) which records 30-meter data in six spectral bands, and 60-meter data in one band. The bands include the blue, green, red and near infrared (NIR) portions of the spectrum (Bands 1 to 4, respectively), and two Bands (5 and 7) in the middle infrared, or short wave infrared (SWIR), range. These all measure reflected energy. The final band (6) records emitted thermal infrared or long wave infrared (LWIR) that registers heat. All bands are spatially co-registered. The orbit is near-polar, with a swath width, or path, recorded across about 180 km. The continuous stream of data for each swath is segmented out into approximately square areas called "scenes" for purchase. A scene covers roughly 32,400 sq km (180 x 180 km) of the earth's surface. The orbital sequence is continual and iterative, such that, repeat coverage for any particular swath is 16 days. Scenes initially are path-oriented, but one can request various levels of geo-rectification, to register a dataset of all bands to a user-specified map projection. Both side-lap and end-lap occurs between adjacent scenes. The latter is typically constant at about 5 percent, while the former increases from the equator toward the poles, within a range of about 5 percent to over 60 percent. Regions that fall within overlap areas can have multiple scene dates for expanded temporal coverage outside of the 16-day interval.

Recent reduction in congressional appropriations may necessitate decommissioning Landsat 5. As a consequence, this source may not be available in the near future. For more information visit the Landsat 5 web site at:

http://www.earth.nasa.gov/history/landsat/landsat5.html

Marketing and pricing of Landsat 5 data used to be fairly complicated. Basically, there were two exclusive sources for the U.S. Scenes more that 10 years old, and all scenes previously purchased by the Federal Government, were available through the USGS EROS Data Center (EDC) outside Sioux Falls, SD. The cost was fixed and relatively inexpensive, ranging between $600 and $800, depending on the post-processing options requested by the buyer. Scenes less than 10 years old, and not previously purchased, were sold by a private company, Space Imaging Corp., formerly EOSAT Corp. Pricing was roughly double the above, at about $1200 to $1600 per scene. One could also order these scenes through EDC. However, the cost included the normal EDC processing, plus a tape origination fee, plus a fee for every scene that preceded the scene of interest on the tape. Since the latter was highly variable, the least cost alternative had to be determined on a case-by-case basis. Presently, all Landsat data is marketed by EDC and costs have been fixed at lower prices. Data are distributed on CD and various tape media.

For ordering and viewing available Landsats 1-5 scenes, check the following web site:

http://edcsns17.cr.usgs.gov/EarthExplorer/

Space imaging continues to sell derived Landsat 5 products, such as map-registered photographs from space, and products from other satellites; their web site is:

http://www.spaceimaging.com/products/25ms.html

Landsat 7

Launched in 1999, Landsat 7 carries an Enhanced Thematic Mapper Plus (ETM+) sensor. It records essentially the same spectral and spatial characteristics for bands 1 through 7 as the TM (above). In addition, ETM+ has a 15-meter panchromatic band, Band 8, spanning the whole visible spectrum (blue through red) in one bandwidth, and an additional thermal infrared band, Band 9 at 60-meter resolution. Orbital and scene characteristics are very similar to Landsat 5, with closely overlapping paths. Overpasses between the two satellites are staggered by 8 days. This provides more frequent coverage for a given area, at least as long as both satellites remain operational. As of May 2003, Landsat 7 developed a scan line corrector problem, which leaves a regular pattern of missing lines within the scenes. The situation has a huge negative impact on fire-related applications, but some of that data may still be useful.

For more information about Landsat 7, see:

http://landsat7.usgs.gov/
http://landsat.gsfc.nasa.gov/

All Landsat 7 data is available through the USGS EROS Data Center near Sioux Falls, SD. Prices for data before May 2003 range between $475 and $800, depending on buyer-specified post processing options. Those include four levels of radiometric and geometric correction. The highest level, "precision corrected", is recommended since some of these procedures are difficult to perform "in-house", and the added cost is low to ensure that all data holdings have been treated in standard and well documented ways. Data are distributed on CD, various tape media, or by ftp over the Internet. There are options for data after May 2003, with the scan line corrector problem, at much lower prices. Consult the USGS EROS Data Center for up to date information.

For ordering and viewing available Landsat 7 scenes, contact either of the two sites:

http://edcdaac.usgs.gov/landsat7/
http://edclxs2.cr.usgs.gov/

LANDSCAPE ASSESSMENT APPENDIX B: OTHER REMOTE SENSING DATA SOURCES

Several remote sensing technologies besides Landsat may be available to address fire management objectives. Applicability depends on scale, scope, and cost requirements, which may different from those of FIREMON Landscape Assessment. For example, continental geographic coverage and daily sampling frequency can be obtained at low cost from AVHRR data. The resolution is 1 km, however, and may be too course for local resource managers.

MODIS, a relatively new sensor geared mostly to global dynamics, may be suited to landscape monitoring of burned areas, but has limited resolution of 250 meters in 2 bands. The remaining 34 bands have resolutions of either 500 m or 1000 m. Currently released data products are provisional data sets, primarily of interest to the research community. Standardization of these products may not be optimal as incremental improvements are still occurring. Moreover, data are not continuously archived, and there is limited availability over designated target sites. The data are presently free, however, and may be worth considering for burn monitoring in some areas.

Detail finer than Landsat can be achieved with 1- to 20-meter resolution from a host of airborne or satellite sensors, including AVIRIS, ASTER, SPOT, and IKONOS. Price is significantly greater than Landsat per unit area. However, these might be appropriate for individual case studies of high ecological or socioeconomic significance, where inter-regional standardization is not so much a concern. Generally, none provide continual continent-wide coverage, and acquisition is intermittent. Missions are contracted project-to-project, and pre-scheduled at designated target areas. Acquisition is usually limited to a few attempts, so unsuitable conditions, like excessive cloudiness, can force cancellation of a mission when adequate data cannot be had in allotted time. Since future fire locations cannot be known, there also is little chance to acquire pre-burn information. That not withstanding, some of these sensors may be added to FIREMON methodology in the future, as they become further developed, and evaluated for routine burn monitoring in a variety of ecosystems.

Refer to the Landscape Assessment bookmark link on the FIREMON website for other references to be found on the Internet.